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A SMUTTY STORY

The biology of head smut of maize and sweetcorn, and options for its control in New Zealand

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Author's note: *This article was commissioned as a 'review' of head smut with particular reference to sweetcorn. A search of literature published over the past 30 years revealed over 200 scientific papers on head smut of maize, but only 10 specifically on head smut of sweetcorn. Because the fungus does not discriminate between hosts, the information relating to maize is equally applicable to sweetcorn and popcorn. In preparing the article I have utilised information from published papers, a number of 'classic' texts on smuts, and drawn on my own experience of over 10 years research on the biology and control of smut fungi in cereals and grasses in Australia, Canada and New Zealand.*

Growers of maize, popcorn and sweetcorn in the Gisborne, Hawkes Bay and Canterbury areas know the end of this particular smutty story only too well – clouds of black spores emerging from the combine, losses in the field and during processing, and smut infested paddocks that constrain cropping options.

The disease is present in all of the major maize and sweetcorn growing districts of New Zealand. It was first recorded in the Gisborne district in 1938 (Anon. 1938). It was recorded from Hawkes Bay in 1972 (Fullerton 1973) and was introduced to the Waikato during the expansion of maize into that area during the 1970s. Although it has been a longstanding problem in maize, losses in that crop are confined to the proportion of infected plants in the field (Fullerton et al. 1974). Sweetcorn growers face not only direct losses in the field, but also deductions to consignments after inspection at the processing plant and, in some cases, rejection of the entire load. In addition, growers face labour costs associated with inspection and rogueing of crops during the growing season to avoid later problems with processing. The failure to detect smutted cobs prior to processing can result in unsightly spore contamination of other cobs in the processing line.

On average, total annual losses in the sweetcorn processing sector from head smut are not great, reaching $30,000 annually in the Gisborne district. However, economic losses to individual growers can be significant. The relatively modest loss industry-wide indicates that current control practices are maintaining a reasonable level of control. Nevertheless, it presents an ongoing and serious threat to the sustainability of the industry. Failure to control the disease will result in a rapid increase in numbers of spores in the soil. Fungicides, even under ideal conditions, control only a proportion (albeit usually a high proportion) of the target pathogen. Under conditions of extreme disease pressure, even the most effective fungicides may fail to provide adequate commercial control. An effective control strategy is necessary to maintain long-term cropping options and the ongoing viability of the industry. This article outlines

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current knowledge of the biology and life cycle of the fungus, and examines options for controlling or managing the disease in New Zealand

Cause

Head smut is caused by the fungus *Sporisorium relianum* f. sp. *zeae* Langdon & Fullerton (=*Sphacelotheca reiliana* (Kühn) McAlpine).

Symptoms

The disease affects both tassels and cobs. On tassels, typical symptoms are a brown or black mass of powdery spores replacing part, or all of the tassel. Cobs are usually swollen and distorted with the spore mass often remaining covered by the husk. The spore bearing structure is known technically as a sorus (plural sori). As the spores are dispersed, a mass of stringy threads composed of fungal and plant tissue remains. Symptoms can be quite variable. Both cobs and tassels are sometimes converted to a bizarre mass of leafy shoots (a condition known as phyllody) intermixed with spores. Spores are sometimes found in the cob but not the tassel and vice versa. In some cases, particularly on cobs, only part of the cob or even some grains may be affected with very little external evidence of infection. Partially infected cobs are a particular problem on sweetcorn as they may escape detection before being husked for processing.

Other common symptoms are stunting of infected plants (Baggett & Kean 1989) and the presence of light yellow or brown, 'greasy' flecks and spots on nodes, stems and along midribs. In some cases small clumps of spores are formed on those spots (Stromberg et al. 1984). The stem and leaf symptoms are useful for diagnosing infection in young plants (Matyac & Kommedahl 1985a).

Infection and disease development

Infection occurs in the soil both from spores carried on the seed and from spores in the soil. Because fungicides used in conventional seed dressings will normally kill spores on the seed, the primary source of infection in commercial crops is spores surviving in the soil from a previous crop.

The plant is susceptible to infection only during the short period between seed germination and the emergence of the first few leaves above ground. There are differences of opinion as to the most important pathway of infection with evidence for infection via roots, the hypocotyl (the small stem between the seed and the node of the coleoptile) and the coleoptile (Podhraszszky 1966, Zhu et al. 1984a, Martinez et al. 2000). It is probable that during the early stage of seed germination all pathways are utilised by the fungus. As seed germination proceeds, the coleoptile node and the coleoptile are likely to become the most important sites as they provide most direct access to the growing point.

Smut spores germinate close to the germinating seed, possibly in response to exudates from the plant (Martinez et al. 2001). Infection hyphae penetrate the host epidermis and extend through the tissues until they reach the growing point. The fungus then remains in that position during the vegetative growth stage of the plant. Smut hyphae grow within the mass of cells behind the growing point that progressively differentiate into stem and leaf tissues. In this way the fungus becomes distributed passively throughout the stems and leaves of the plant. Although hyphae of the fungus can be found in almost any part of an infected plant they do not actively grow in mature plant tissues such as stems and leaves. The yellow, 'greasy' flecks and spots observed on nodes internodes and leaves of infected plants correspond to isolated islands of fungal hyphae located in those plant parts.

Head smut has a special association with the inflorescence of the host. A short description of the growth habit of maize will help to understand how the disease finally appears in the tassels and cobs. A maize plant (as in all grasses) has two distinct growth phases, a vegetative phase and a subsequent floral, or reproductive, phase. The transition from the vegetative to the reproductive phase is marked by the elongation of the terminal growing point and of the primordial axillary buds to form the tassel and cob initials respectively. The transition from vegetative to floral growth takes place very early in the life of the plant, usually when about 12 leaves or leaf initials have been formed, and the plant is 30-40 cm in height. At that stage all the vegetative structures found in the mature plant (nodes, leaves, axillary buds) have been initiated and are at varying stages of development, and the plant is in a very 'compressed' state. Subsequently, the internodes lengthen, and there is progressive emergence of the leaves and finally the tassel and the cobs.

The transition from vegetative to reproductive growth in the plant stimulates the fungus to enter its reproductive phase. From its position in the cells immediately behind the growing point it moves rapidly into the elongating floral initials of the tassel and cobs. The fungus grows throughout the floral tissues, forming large masses of hyphae (sporogenous hyphae) from which spores will later develop. This process continues during growth and elongation of the plant, simply following the normal developmental processes of cobs and tassels. At the surface of the developing floral organs a specialised layer of fungal tissue develops several layers of cells below the epidermis. That layer, together with the outer plant cells forms a white membrane, the peridium, which surrounds the developing mass of spores. Internally, the sporogenous hyphae continue to proliferate around remnants of plant material, particularly the vascular tissues. This pattern of development results in spores of different maturity in the sorus, the most mature adjacent to the peridium, the youngest close to the inner threads of host tissues. When the sori in cobs and tassels emerge from the plant the peridium splits, releasing the dry, dusty spores (Fullerton & Langdon 1975, Matyac 1985, Martinez et al. 1999).

The range of symptoms observed in cobs and tassels reflects the distribution of the fungus in the tissues at the early stages of floral development. Some parts, or occasionally the whole organ, may escape invasion by the fungus.

Spore dispersal.

The small, dry, dusty spores of smut fungi are typically airborne and can be carried to high altitudes and over long distances. There are examples of spores of some smut species being recovered at altitudes of over 11,000 feet, and from the air over arctic and sub-arctic regions (Fisher & Holton 1957). With combine harvested maize the majority of spores remain close to where they were formed either returned to the soil in the same paddock or windblown to adjacent paddocks. Movement to more distant areas is most often due to spores on untreated seed, or the movement of spore contaminated machinery and soil.

Longevity of spores

Spore longevity is dependent on various factors such as soil type, moisture content and temperature. The number and viability of spores decrease relatively quickly in the absence of a crop. In Minnesota, spore numbers decreased by 42% within the first six months and fell to 4% after four years (Matyak & Kommedahl 1986). In the same study, spore viability fell by 90% after six months of high moisture content and temperatures of 25°C. The incidence of plant infection is linearly related to the logarithm of numbers of spores in the soil, with a threshold of 800g spores/gm of soil for infection (Al Sokaily 1984). Considering the huge numbers of spores returned to the soil from a heavily infected crop, it could be expected that, even after several years fallow or rotation, adequate numbers of spores would survive to initiate infection in the next crop.

Although there is no experimental evidence for the fate of head smut spores ingested by livestock, spores of other smut species do not survive passage through the alimentary canal of animals. In fact, animal manures have been shown to have a stimulatory effect on germination of smut spores (Fisher and Holton 1957).

Infection conditions

The success of infection is governed by a number of factors, some directly affecting the fungus, others affecting the growth rate of the plant. Infection can take place over a temperature range from of 14-35°C with an optimum range of 21-28°C (Halisky 1962). In general, drier soil conditions favour infection. High soil moisture for the first 3 weeks after planting and high soil temperatures have been shown to reduce infection (Baier & Krüger 1962, Mack et al.1984). Soil type also has an effect, with infection being favoured more by sandy soils than loams and clays (Kruger 1969, Matyac & Kommedahl 1985b).

The period during which the fungus can infect maize or sweetcorn is quite short. The faster plants pass though the susceptible stage, the less opportunity there is for infection (Zhu et al. 1984b). Conversely, any conditions that slow germination and emergence such as deep planting (Mack et al 1984), poor aeration or soil compaction will promote infection. The effect of soil compaction is commonly observed in maize in the Gisborne district, where there is typically a higher incidence of infected plants around gateways than in the body of the paddock.

Control

Options for control of head smut fall into three categories: cultural, chemical, and use of resistant varieties.

Cultural control.

A number of cultural practices can assist in minimising smut survival and infection. Rotations are the most effective means to reduce the background numbers of spores in soils. Research in Russia (Popov 1968) showed that when maize was rotated with wheat, smut infection was reduced to 0.8% compared with 10% under continuous maize cropping. Nevertheless, experimental evidence shows that biologically significant numbers of spores may remain in some soils for over four years (Matyac & Kommedahl 1986). The economic pressures of commercial production often prevent growers adopting long-term rotations. There is evidence that some fertilizers (e.g. urea, sulphate of ammonia, triple superphosphate) can reduce infection while others (e.g. calcium nitrate) tend to increase it (Popov 1968, Matyac & Kommedahl 1985b). The effects, though statistically significant, are usually slight and, under commercial conditions, unlikely to be economic as a 'control' measure.

There are no 'magic bullets' for the cultural control of head smut. Any practice that reduces the number of spores surviving in the soil and enhances the growth rate of the plant will contribute to the efficacy of control achieved by other measures such as seed treatment and resistant varieties.

Fungicides

Choice of fungicides. Fungicides with label claims for the control of smut diseases in cereals, including maize and sweetcorn in New Zealand are shown in Table 1 (Walton 2001). Fungicides shown experimentally to provide effective control of head smut elsewhere are shown in Table 2.

Table 1. Fungicides with New Zealand label claims for control of cereal smuts.

Product	Active ingredient	Chemical Group	Crop	Disease
Baytan Universal®	triadimenol 150 g/l imazalil 100g/l fuberidazole 100g/l	triazole imidazole triazole	Wheat Barley Oats	Loose smut, stinking smut Loose and covered smut Loose and covered smut
Raxil®	tebuconazole 25g/l	triazole	Wheat Barley Oats	Loose smut, stinking smut Loose and covered smut Loose and covered smut
Vincit®	flutriafol 500g/kg imazalil 50g/l	triazole imidazole	Wheat Barley Oats	Loose smut, stinking smut Loose and covered smut Loose and covered smut
Vitaflo 200®	carboxin 200g/l thiram 200g/l	carboxanilide disulphide	Maize	Head smut
Benlate®[1]	*benomyl 500g/kg*	*benzimidazole*	*Maize*	*Head smut*

[1] no longer available.

Table 2. Fungicides shown to provide control[1] of head smut in various countries.

Product	Active Ingredient	Group	Country	Reference

Baytan®	triadimenol	triazole	China Mexico Nepal Romania	Song et al. (1987) Martinez & Ledesma (1990) Pradhanang & Ghimire (1996) Pelmus & Pelmus (1988)
Bayleton®	triadimefon	triazole	China	Song et al. (1987)
Tecto®	thiabendazole	benzimidazole	Mexico	Martinez & Ledesma (1990)
Tilt 250®	propiconazole	triazole	Mexico Nepal Nepal USA	Martinez & Ledesma (1990) Ghimire & Harding (1997) Pradhanang & Ghimire (1996) Steinstra et al. (1985)
Vitavax 200®	carboxin +thiram	carboxanilide disulphide	Mexico Romania	Martinez & Ledesma (1990) Pelmus & Pelmus (1988)
Vitavax 75®	carboxin	carboxanilide	Romania	Pelmus & Pelmus (1988)
Tiradin 75®	thiram	disulphide	Romania	Pelmus & Pelmus (1988)
Atout granular®	flutriafol +carbofuran	triazole carbamate	France	Naibo & Delalondre (1992)
Sumi-8®	diconazole	triazole	Nepal	Pradhanang & Ghimire (1996)
Raxil	tebuconazole	triazole	Nepal	Pradhanang & Ghimire (1996)
Alios®	triticonazole	triazole	France	Mugnier et al. (1994) Schneider et al. (1998)

[1] Information based on published trial data. It does not indicate that the fungicides are being used commercially for head smut control in those countries.

Seed treatment with fungicides is the normal method of controlling head smut of maize and sweetcorn in New Zealand. For almost thirty years, the industry has been reliant on two products, Vitaflo (carboxin + thiram) and Benlate (benomyl). The current recommendations are largely based on experimental work conducted by the author and colleagues in 1973 (Fullerton et al. 1974). With the withdrawal of Benlate from the market in 2001, there is now only one product that can be used for smut control on maize and sweetcorn.

The information in Tables 1 and 2 indicates that there are a number of effective alternatives available. Several fungicides belonging to the chemical group known as 'triazoles' are highly effective against smut diseases with some (triadimenol, tebuconazole, flutriafol) routinely used for smut control in the small grain cereals in New Zealand. Those fungicides, together with propiconazole (Tilt) which has a good record of control elsewhere, and is readily available in Zealand, should be the first choice for evaluation and registration for control of head smut in New Zealand. While there are others with demonstrated efficacy, for economic reasons, agrichemical companies are unlikely to invest in developing or registering new products for the relatively small maize and sweetcorn industry.

Triazole fungicides have a reputation, as a group, for causing phytotoxicity in seedlings. Phytotoxicity can be influenced both by the formulation and soil conditions at planting. High soil moisture, low temperatures and deep planting can increase the risk of phytotoxicity in maize (Song et al. 1987). It will be necessary to determine the most appropriate formulations and application rates for maize to provide a safe balance between efficacy of disease control and phytotoxicity under New Zealand conditions.

Seed treatment vs. soil application. Fungicides for control of soil-borne diseases are generally applied either to the seed, or to the soil as soil sprays or granular formulations. Application of fungicide directly to the soil is effective against head smut. Steinstra et al. (1985) achieved good control in Minnesota using in-furrow applications of a granular formulation of propiconazole (Tilt). In France, Atout (flutriafol + carbofuran) provided good control of head smut when applied in-furrow (Naibo & Delalondre 1992). However it was noted that control could be improved by its use in combination with seed treatment.

In general, seed treatment, is the most convenient and economical option. Accurate application rates can be achieved with minimal quantities of product, and no additional operations or equipment are required at planting. In addition, seed application of triazoles may have additional advantages. A study of mode of uptake of the fungicide triticonazole (as Alios) in France (Schneider et al. 1998) showed that the fungicide does not enter the seed directly but diffuses into the soil whence it is absorbed by the roots and translocated upwards into the coleoptile and young shoot. As a result, the movement of the fungicide into the plant tissues coincides with the time of infection of the roots, hypocotyl or coleoptile. With soil applications, particularly soil-surface applications, there is likely to be a delay between application of the fungicide and its availability in the root zone. The delay may be considerable if dry conditions are experienced after planting. In practice, the choice of method will depend largely on the formulation available. At present, there are no granular formulations of the candidate triazoles available for head smut control in New Zealand.

Chitosan seed treatment.

A novel control method evaluated in China (Jiang et al. 1994) involved the soaking of seeds in a 1% solution of chitosan. The treatment stimulated germination, inhibited infection by maize smut and increased yield by 20%. Chitosan is an extract from the shells of crustaceans and acts by inducing a general resistance response in the plant. When a fungus attempts to infect the plant it is confronted by a preformed battery of defense compounds within the tissues. It is unlikely that the yield response achieved in the above study was due to control of head smut alone. The resistance induced is non-specific, providing protection from a wide range of soil-borne organisms. Chitinase is also known to have a direct biostimulatory effect on some plant species after seed or soil treatment (Chibu et al. 1999, Reddy et al. 1999).

Resistant varieties

In the long term, use of resistant varieties offer the most economical and sustainable method of combating head smut. Resistance in maize and sweetcorn has been shown to be controlled by a number of genes that have additive effects (Whythe & Gevers 1986, Akhtar & Baggett 1990). With resistance of that kind, plants are not immune to the disease but will sustain a low percentage of infection. Any percieved disadvantages of the low level of infection is offset by the security offered by multigenic resistance. That type of resistance tends to be 'durable' and not easily overcome by mutations within the pathogen.

The development of smut resistant hybrids is much further advanced for maize than for sweetcorn. This probably reflects the global economic importance of maize compared with sweetcorn. A number of maize varieties available in New Zealand carry high resistance against head smut. Resistance ratings are normally included in the specifications of the hybrids in the seed catalogues. Most information relating to resistance in locally available sweet corn varieties is anecdotal, based on field experience over a number of seasons in smut infested fields. Growers intending to plant in smut infested land should source and plant only hybrids that have credible resistance ratings.

There are a number of field and glasshouse screening methods available for assessing the relative resistance of maize and sweetcorn to head smut (Baggett & Koepsell 1983, Matyac & Kommedahl 1985a). Where specific information on resistance is lacking, comparative tests could be carried out relatively easily.

Conclusions

1. Head smut causes relatively low but consistent losses in the maize and sweetcorn industry at the national level, reflecting relatively successful control by current seed treatment and management practices.
2. Because of its ability to increase rapidly in the absence of control measures, it presents an ongoing threat to the long-term sustainability of those crops.
3. Fungicidal control in maize and sweetcorn has been reliant on only two products (Vitaflo and Benlate) for almost 30 years. With the withdrawal of Benlate from the market, the industry is now reliant on only one fungicide for seed treatment. This introduces a high measure of vulnerability to the industry.
4. The maize and sweetcorn industries in New Zealand have not kept pace with the other cereal industries in the uptake of new fungicides for smut control.
5. Evaluation and registration of alternative fungicides for smut control should be regarded as an industry priority.
6. A number of alternative fungicides, particularly those belonging to the triazole group, have strong activity against smut diseases and have been shown to be effective against head smut elsewhere in the world.
7. Several of those fungicides are already registered for use against smuts of other cereals in New Zealand and would be readily available for efficacy testing in maize and sweetcorn.
8. There are a number of maize hybrids available in New Zealand with specific ratings for smut resistance. There is much less information available on smut resistance in locally available sweetcorn hybrids.

Recommendations.

1. Conduct efficacy testing of the fungicides already registered for use against smuts on other cereals in New Zealand (Baycor, Raxil, Vincit). In addition the fungicide propiconazole (Tilt), shown to have strong efficacy against head smut elsewhere (and available in New Zealand) should be included in the programme.
2. Plant only hybrids with credible resistance ratings against head smut in infested land.
3. Conduct comparative resistance evaluations of maize and sweetcorn hybrids that are particularly valuable to the industry, but for which no experimental data on resistance are available.
4. Employ appropriate cultural measures wherever possible to minimise infection, including crop rotations to reduce spore numbers in the soil and provision of conditions to promote rapid growth of seedlings.

Through a combination of farming practices suppressive of the disease, the use of resistant varieties, and the registration of one or more 'new' fungicides to provide backup to Vitaflo for seed treatment, the long term sustainability of the maize and sweet corn industries should be restored.

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